Designing and Fabrication of Double Pass Solar Air Heater Integrated with Thermal Storage

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Abstract: ***This research work is to create a working model of the active type, solar air heater with the capacity of thermal storage. Paraffin wax is used as the thermal storage material. Blower is used for forcing air into the air heater. The ideal material for better conductivity is analyzed for its properties and used. Aluminium was used for collector plate due to its high thermal conductivity. This work enhances the efficiency of solar air heater as it was designed for heating the atmospheric air twice and also the environmental changes like disturbance in the continuous expose of Sun rays to the collector plate by clouds has not affect the heating temperature as the thermal storage kit was implemented. The readings were taken by using thermocouples. Thus a model solar air heater was developed and tested to have an efficiency of 70 %.***

Keywords: Solar air heater, Thermal storage, paraffin wax, Blower, Aluminium, Collector plate, Thermocouple.

1. Introduction

Both living and non living things are in need of energy in some form. They have the capacity to do the work by the utilization of some energy. Need of energy has become the basic feature for everything in the world.

Universe is filled with energy of various varieties. . The threat of extinction of the conventional sources of energy has paved way for seeking alternate sources of energy. Of this alternate energy sources the most predominant one is the radiant energy in the form of radiation from the sun which includes light and heat.

Solar radiation has been used in industries for distillation of sea water, producing electricity, boiling water and so on. For house hold purposes solar energy usage in not a very common thing. A small electric heater can consume about 3000 watts per hour. In the condition of growing energy crisis this system poses a great threat to the saving of electricity for future generations. Space heating for residential and commercial applications can be done through the use of solar air heating panels. This configuration operates by drawing air from the building envelope or from the outdoor environment and passing it through the collector where the air warms via conduction from the absorber and is then supplied to the living or working space by either passive means or with the assistance of a fan.

Lovemore Kagande, Ignatio Madanhire, Canicius Matsungo [1] in their research study investigated the possibility of solar energy replacing other sources of energy such as thermal and hydro electric energy in domestic water heaters. Other than it being a renewable and cheaper alternative source of energy, solar energy has no documented polluting effect on its generation thus contributing positively to cleaner production for sustainable development, reduction in green house gas emission and potential cost savings. Economic comparative work on its use has been dealt with in air and water heating, and it has been found out that it can be utilized and result in appreciable power savings as well as effectively complementing existing supply sources.

Nabila Ihaddadene, Razika Ihaddadene, Azzeddine Mahdi, [2] in their research paper, an attempt has been made to come across the effect of multiple glazing covers on the efficiency of a solar thermal collector. This experimental investigation was carried out on an active solar energy demonstration system (ET 200), illuminated with a halogen lamp. Three commercial glass panes of 3 mm thickness, having the same dimensions as that of the apparatus glazing, were used. Tests were done with and without the added glass panes, at a fixed water flow rate of 5.8 l/h, taking the whole surface of the collector maintained at an horizontal position. Experiments were performed with two positions of the light meter. In one position, it was placed in the middle of the collector surface. While, in the other, the light meter was placed in the middle of the upper glass added. Double, triple and quadruple glazing, reduce the amount of heat absorbed by water by deceasing water temperature difference between the inlet and outlet of the absorber. Double glazing decreased the efficiency of the solar collector with 15%. This efficiency was decreased by 29,95% for triple glazing, and by 45,96% for quadruple glazing. The addition of glass panes above the collector surface, acts as a resistance to the spread of the energy transmitted by the halogen lamp, this effect reduces the performance of the solar collector instead of improving it, according to a linear equation with a high correlation coefficient.

Vijaykumar Kalwa, R. Prakash [3] presented air cooling methods are evaporative coolers, air conditioning, fans and dehumidifiers. But running these products need a source called electricity. The producing of electricity is ultimately responsible for hot and humid conditions i.e. global warming. In hot and humid conditions the need to feel relaxed and comfortable has become one of few needs and for this purpose utilization of systems like air-conditioning and refrigeration has increased rapidly. These systems are most of the time not suitable for villages due to longer power cut durations and high cost of products. Solar power systems being considered as one of the path towards more sustainable energy systems, considering solar-cooling systems in villages would comprise of many attractive features.

Rajesh Thombre, Gajanan Awari, Shashikant Thombre [4] aimed at studying the effect of different system parameters on the heat transfer on vertical circular tube air heater. They include tube length, tube diameter, and heat flux supplied. Constant heat flux boundary condition is created on the tube surface. Experiment is conducted to investigate the effect of different system parameter on heat transfer and buoyancy induced flow. The heat transfer coefficient was found increasing with increase in heat flux supplied, but it reduces with increase in diameter of the tube and its length. The air outlet temperature was found increasing with increase in heat flux, tube length but reduces with increase in tube diameter. Nusselt number is calculated and was found well within 10% of the results given in the literature.

D.S.Rawat, Dr.A,R.Jaurker [5] presented in their paper investigated heat transfer enhancement in two pass solar air heater with V-shaped rib. Ribs were attached on absorber plate, having angle of attack. Air enters the upper channel of the air heater and subsequently to the lower channel in the opposite direction. Roughened wall of the duct is uniformly heated with constant heat flux electric heater while the remaining three walls are insulated. The heat transfer results have been compared with those for smooth ducts under similar flow and thermal boundary conditions.

1.1 Environmental Characteristics

The sun is a sphere of intensely hot gaseous matter with a diameter of 1.3 X 10 ^{9} m. The sun is about 1.5X10^{8} km away from the earth and hence thermal radiation travel with the speed of light in a vacuum. After leaving the sun solar energy reaches the earth in 8 minutes and 20 seconds. As observed from the earth, the sun disk forms an angle of 32 minutes and 1 degree. The sun has an effective black body temperature of 5760 k. The temperature in the central region is much higher. This temperature of the sun is due to the fusion reaction between hydrogen atoms that produce helium. The suns output energy is about 3.8 X 10^{20} MW, which is equal to 63 MW/m^{2} of the sun's surface. This energy is transmitted radially outwards in all directions. Only a tiny fraction of energy is received by the earth which is about the order of 17 X 10^{14} KW. However even with the small fraction it is estimated that 84 min of solar radiation falling on the full earth surface is equal to the world energy demand for one year (about 900 EJ). As seen from the earth the sun rotates around its axis once in every four week.

As observed from the earth, the path of the sun across the sky varies throughout the year. Knowledge of the suns path around the sky is necessary to calculate the solar radiation falling on the surface, heat gain by the plate, the placement to avoid shading and many more factors. The environment in which a solar system works depends mostly on the solar energy availability. The general weather of a location is required in many energy calculations.

1.2 Solar Air Heating

Solar air heating is a renewable energy heating technology used to heat or condition air for buildings or process heat applications. It is typically the most cost-effective out of all the solar technologies, especially in commercial and industrial applications, and it addresses the largest usage of building energy in heating climates, which is space heating and industrial process heating. Solar air collectors can be commonly divided into two categories:

- Unglazed Air Collectors or Transpired Solar Collector
- Glazed Solar Collectors

1.2.1 Unglazed Air Collector

Unglazed air collectors heat ambient (outside) air instead of recirculated building air. Transpired solar collectors are usually wall-mounted to capture the lower sun angle in the winter heating months as well as sun reflection off the snow. The exterior surface of a transpired solar collector consists of thousands of tiny micro-perforations that allow the boundary layer of heat to be captured and uniformly drawn into an air cavity behind the exterior panels. This heated ventilation air is drawn under negative pressure into the building's ventilation system where it is then distributed via conventional means or using a solar ducting system.

1.2.2 Glazed Air Collector

Functioning in a similar manner as a conventional forced air furnace, systems provide heat by recirculating conditioned building air through solar collectors – Solar thermal collectors. Through the use of an energy collecting surface to absorb the sun's thermal energy, and ducting air to come in contact with it, a simple and effective collector can be made for a variety of air conditioning and process applications. A simple solar air collector consists of an absorber material, sometimes having a selective surface, to capture radiation from the sun and transfers this thermal energy to air via conduction heat transfer. This heated air is then ducted to the building space or to the process area where the heated air is used for space heating or process heating needs.

Applications such as space heating, greenhouse season extension, pre-heating ventilation makeup air, or process heat can be addressed by solar air heat devices. In the field of 'solar co-generation' solar thermal technologies are paired with photovoltaic (PV) to increase the efficiency of the system by cooling the PV panels to improve their electrical performance while simultaneously warming air for space heating.

Solar air heat can also be used in process applications such as drying laundry, crops and other drying applications. Air heated through a solar collector and then passed over a medium to be dried can provide an efficient means by which to reduce the moisture content of the material. Many detached suburban houses can achieve reductions in heating expense without obvious changes to their appearance, comfort or usability.

2. Problem Definition and Methodology

The process of room heating is a must in winter for every home. Due to the changing environmental conditions winters have become severe nowadays. Also the room heating with conventional fuels has turned out to be costly due to the raging fuel crisis. Hence an efficient solar air heating device must be created which can be used to household purposes. The air heater is made to work on solar energy which is a renewable form of energy. There must also be a provision for storing thermal energy and utilizing it at times of need.

Double pass method is used for receiving heat and increasing its temperature independently. Aluminium is used as the solar heat collecting material and it is made to have a number of cylindrical pipes above it so as to have an efficient thermal storage. Paraffin wax is used as the thermal energy storage material. The entire apparatus is blackened out from the inside so as to ensure the entrapping of solar energy. The setup is made to behave as a two chamber setup so as to prevent leakage of air directly from the entrance to exit. Glass is used for covering the apparatus from the top, which allows light rays to pass through but traps the heat from escaping. There is also a provision for measuring the quantity of air entering into the apparatus and to measure the temperatures at various sections of the apparatus.

3. Description of the Equipment

3.1 Chamber

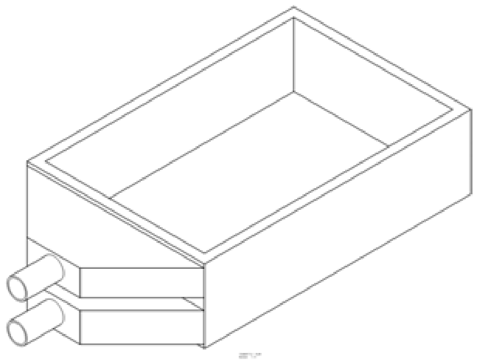

Figure 1: Isometric View of Chamber

The chamber of the solar air heater is made up of cast iron. The chamber is of rectangular in shape.

The dimension of the cast iron box is
Length of the box (L) : 73 cm
Breadth of the box (B): 45.5 cm
Thickness of the box (T): 17 cm

This rectangular shape is made because a it can hold more air and also it is easy to construct. The block is placed with insulating material of glass wool along all sides. This is done so as to prevent the heat from escaping outwards. Then aluminium sheet of 2 mm gauge diameter is placed along the sides of the box and along the bottom. Aluminium sheet is used, since aluminium is a best conductor. The inside of the box is then blackened out to encourage conduction.

Volume occupied by the chamber =L X B X H
=73 X 45.5 X 17
=0.057 m^3

This chamber is split into two halves, chamber 1 and chamber 2. The chamber 1 which is below is for preheating of air and the chamber 2 that is above is for final heating of air.

Thus the volume occupied by each chamber = (0.057/2)
=0.0285m^3

3.2 Collector Plate

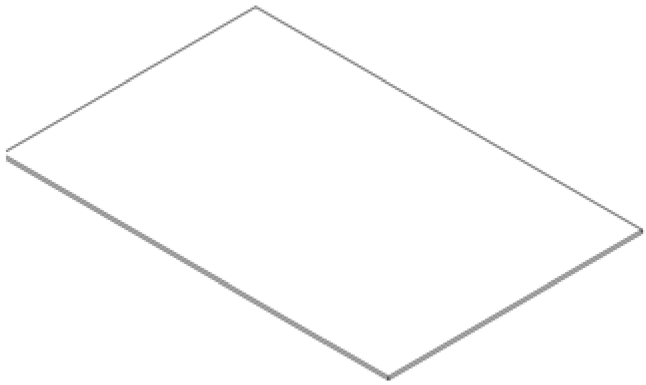

Figure 2: Collector Plate

The collector plate used is a flat plate collector with no reflector. The material for the collector plate is aluminium. The dimensions of the absorber plate are,

Length of the plate : 64 cm
Breadth of the plate : 45 cm
Thickness of the plate: 0.4 cm

Therefore surface area in contact with air passing out
=64 X 45
= 0.28 m^2

Table 1: Comparison of Thermal Conductivities of Various Metals

Material	*Thermal Conductivity*
Copper	386 W/mK
Aluminium	202.5 W/mK
Brass	110.7 W/mk
Bronze	25.9 W/mK
Carbon steel	63.9 W/mk

Copper is known to have higher thermal conductivity but due to its high cost it is not used. Next to copper stands aluminium with a better thermal conductivity value. The other metals like brass, bronze and carbon steel have low thermal conductivity value and are difficult to process. That leaves with the choice of aluminium. Hence is chosen according to the requirements.

3.3 Thermal Storage Pipe

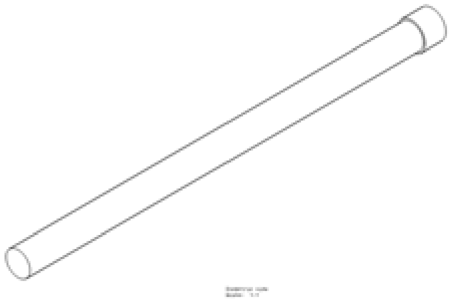

Figure 3: Thermal Storage Pipe

Thermal storage is the process of storing the heat energy when available in excess. This thermal storage is used to maintain same temperature of the exit air when the sunshine in not at peak. This is made possible by the use of phase change material. Phase change material (PCM) is one that is capable of changing its state on observing heat and liberates the heat by returning to its original state. Paraffin wax is used as a PCM in this project.

Table 2: Chemical properties of wax

Material	Wax
Melting point	46 ^{0}C
Density	0.9 g/cm^3
Specific heat capacity	2.9 Jg^{-1}k^{-1}
Heat of fusion	220 Jg^{-1}

At room temperature paraffin wax is in solid state. But when it comes to contact with air it absorb sensible heat. When temperature reaches around 50^{0}C the heat becomes latent and hence phase change occurs. Thus the solid paraffin changes to liquid paraffin. After this the wax remains in the molten state. When there is a fall in sunshine the temperature of the wax reduces. Thus it starts to solidify by liberating the heat to the surroundings. This paraffin wax is stored in a cylindrical tube and attached with the collector plate. Cylindrical tubes were used so as to ensure the maximum exposure of surface area to the sun.

The dimensions of the cylindrical tubes are
Length of tube : 55 cm
Diameter of the tube : 3.5 cm

The tubes are placed in contact with the collector plate at equal distance from each other. There are about six pipes placed above the collector plate. These pipes are made up of aluminium and are blackened on the outer surface. One end of the pipe is a permanently sealed and the other end temporary sealed is made so as to satisfy the need of refilling wax.

4. Fabrication Process

By performing various machining processes, every parts of the air heater are fabricated based on the design and dimensions.

Table 3: Process Preformed on Various Parts

S.No	*Parts*	*Material used*	*Process done*
1	Chamber	5 mm gauge thickness galvanized iron sheet	Bending, welding, cutting
2	Collector plate	4 mm thick aluminium plate	Cutting, filing
3	Thermal storage pipe	3.5 cm diameter aluminium pipe	Facing, turning
4	Frame	Galvanizaed iron plate	Cutting, bending, drilling
5	Glass	5 mm thickness saint gobain glass	Cutting

5. Assembly

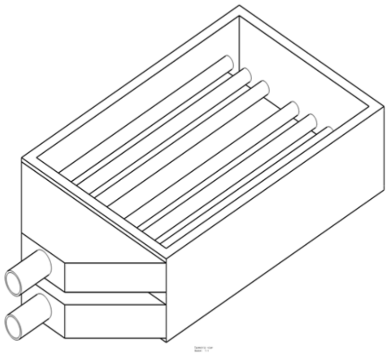

Figure 4: Assembled View of Solar Air Heater

Figure 5: Image of Fabricated and Assembled Solar Air Heater

The outer rectangular box is welded to each other and folded at its sides. The L-shaped frame is attached along the sides and is bolted along the sides. Above it the collector plate is placed and sealed along the corners. Then the thermal storage material cylinder is placed above it by using proper adhesive. Then thermocouple for noting down the various readings are placed and made to stick. Finally glass is placed above the entire apparatus and sealed. The readings from various thermocouples are taken out and connected to the multimeter to find out the temperature of the sections.

6. Working

The air blower was switched ON; the atmospheric air got sucked and sent into the heater through the lower channel. The velocity of the air coming out of blower is measured by anemometer. The heat absorbed by the collector plate from Sun radiation is transferred to the air in the lower channel of the chamber, and then the heated air moved to the upper chamber in the opposite direction and again got heated more as it get recirculated. If the cloud distracts the Sun radiation it did not affect the heat transfer rate as the heat absorbed by the paraffin wax in the thermal storage pipe release sufficient heat to the air. The heated air exits through the pipe in the top channel. The temperature of the incoming and exiting air was measured by thermocouple. The reading is taken for every 30 minutes and tabulated as follows,

Table 4: Observed Readings for every 30 Minutes

Reading	*Time*	*Sun Meter Reading*	*Air Inlet Temperature*	*Air outlet Temperature*
Unit	*A.M*	*W/m^2*	*^0C*	*^0C*
1	9:00	992	32	42
2	9:30	994	32	45
3	10:00	1002	33	50
4	10:30	1006	33	52
5	11:00	1005	33	52
6	11:30	1008	33	55
7	11:59	1010	33	58

7. Result

The velocity of air coming out of the blower is found by anemometer,
Velocity, c = 4.7 m/s
The atmospheric pressure of air, P = 1.013 X 10^5 Pa

The mass flow rate of the air entering the blower is given by,
m = ρAC

Density, ρ = P / (RT)
=1.013 X 10^5 / (287 X 303)
= 1.16 kg/m^3

Therefore mass flow rate = 1.16 X (π/4) X 4.5^2 X 10^{-4} X 4.7
= 8.7 X 10^{-3} kg/s
Inlet temperature of air = 33^0C
Outlet temperature of air = 58^0C

Heat transfer, Q = $mc_p\Delta T$
= 8.7 X 10^{-3} X 1005 X (58-33)
= 218.58 W

Efficiency, Ƞ = Q / (i X A)
From sun meter, i = 1010 W/m^2
Area = 0.288 m^2
Therefore, Ƞ = 218.58/290.88
= 75.15 %

By following above calculation method, the efficiency of the solar air heater was calculated and tabulated for various observed readings as follows,

Table 5: Efficiency of Solar Air Heater

Reading	*Sun Meter Reading i*	*Temperature difference, ΔT*	*Heat Transfer Q*	*Efficiency Ƞ*
Unit	*W/m^2*	*^0C*	*W*	*%*
1	992	10	87.435	30.60
2	994	13	113.665	39.71
3	1002	17	148.64	51.51
4	1006	19	166.127	57.34
5	1005	22	192.357	66.46
6	1008	22	192.357	66.26
7	1010	25	218.58	75.15

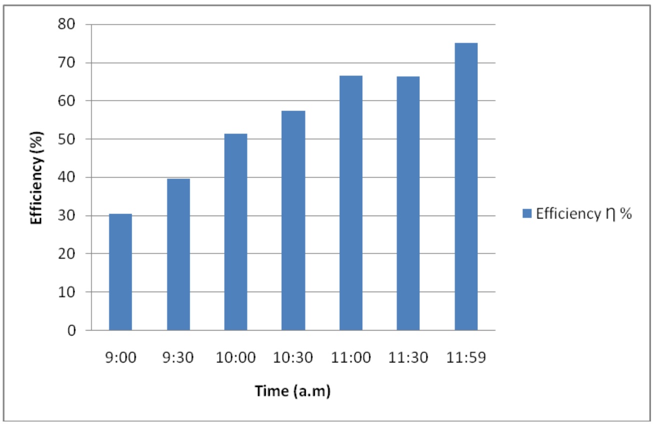

Figure 6: Graph plotted for Time Vs Efficiency

8. Conclusion

Thus by following all the design procedures the solar air heater was designed and fabricated. The results on every aspect of the solar air heater were portrayed. The efficiency of the solar air heater was found to be of 75 % under test conditions. Hence this solar air heater can be used for laboratory purposes.

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